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TECHNICAL REPORT NO. 3-664

HELICOPTER DOWNWASH BLAST EFFECTS STUDY

by

G. W. Leese

October 1964

Sponsored by

U. S. Army Transportation Research Command

Conducted by

U. S. Army Engineer Waterways Experiment Station
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ARMY MRC VICKSBURG MISS

FOREWORD

The study reported herein was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) for the U. S. Army Transportation Research Command. Specific authorization for the study was given by the latter organization in first indorsement dated 7 November 1960 to WES letter dated 27 September 1960, subject, "Proposal for Downwash Blast Effects Study."

Field tests to obtain prototype data on velocities of the downwash blast of various types of operational helicopters were conducted at Fort Rucker, Ala., during March and June 1961 and at the WES in April 1962. Tests with small-scale model rotor blades were conducted in the Surface Effects Blast Facility of the WES during fiscal years 1961 and 1962. No funds were available for testing during fiscal year 1963. These tests were conducted by personnel of the WES Soils Division under the supervision of Messrs. W. J. Turnbull, W. O. Shockley, A. A. Maxwell, W. L. McInnis, O. W. Leese, and P. J. Vedros, Jr. This report was prepared by Mr. Leese.

Directors of the WES during this study and the preparation and publication of this report were Col. Edmund H. Lang, CE, and Col. Alex G. Sutton, Jr., CE. Technical Director was Mr. J. B. Tiffany.

CONTENTS

SUMMARY

Experience with helicopters has shown that during landing or takeoff over dust- or snow-covered areas, the downwash blast from the helicopter rotors produces dust or snow clouds that obscure visibility sufficiently to cause unsafe operating conditions. Recirculation of the dust-laden air through the engine can damage the engine and shorten its life; foreign objects picked up by the downwash can damage the aircraft and even cause its failure as the objects are ingested in the engine or blown against the aircraft's rotor.

Field tests were conducted with operational helicopters at Fort Rucker, Ala., and at the Waterways Experiment Station to determine downwash velocity profiles. In addition, tests utilizing scale-model rotor blades were made at the WES over wet and dry sands and a dry lean clay, and over a chemically stabilized soil, plastic-impregnated soils, and lightweight ground covers (membranes) to determine model-scale velocity profiles and air velocities at the ground surface required to dislodge and move particles of various types of soil, the size of soil area requiring protection for various VTOL aircraft, and the effectiveness of membranes and soil stabilization in preventing dust-cloud formation.

Based on results obtained in this investigation, the following conclusions are believed warranted:

a. The downwash velocities along the ground surface cause soil-particle pickup, and dust hazard conditions will develop if these velocities exceed 1200 fpm over fine dry sand and 1800 fpm over dust-size particles of lean clay.

b. Lightweight ground covers can alleviate dust in the landing and takeoff area of helicopters. A vertical lip around the edge of the membrane will reduce the size of membrane section needed.

c. Certain soil stabilizers will alleviate dust formation under rotary-wing aircraft.

d. Tests to correlate model and prototype data produced limited results. They indicated the need for more accurate measurement of prototype data for each aircraft in order to analyze completely the various parameters involved in scaling and to establish those of paramount importance, so that small-scale tests can be used to predict downwash blast effects of full-scale aircraft.

It is recommended that additional tests be conducted with larger diameter model propellers and with prototype aircraft under rigidly controlled conditions of position and weight in order to establish model-to-prototype prediction curves or equations, or both. Studies should also be continued to determine the factors involved in initial soil-particle pickup and the velocities that cause pickup of various soils in order to predict the area protection required for various helicopters.

HELICOPTER DOWNWASH BLAST EFFECTS STUDY

PART I: INTRODUCTION

Background

1. The operation of helicopters and VTOL*-type aircraft from unprotected soil surfaces presents certain safety and concealment problems which are unique to these types of aircraft. Experience with helicopters has shown that during landing or takeoff over dust- or snow-covered areas, the downwash blast from the helicopter rotors produces dust or snow clouds that obscure visibility sufficiently to cause unsafe operating conditions. Recirculation of the dust-laden air through the engine can damage the engine and shorten engine life; foreign objects picked up by the downwash can damage the aircraft and even cause its failure as the objects are ingested in the engine or blown against the aircraft's rotor. Since helicopters and VTOL aircraft are to be used tactically in support of forward ground operations, dust control is also desirable for camouflage and concealment purposes.

2. The downwash blast of such aircraft varies widely in velocity, mass flow, and temperature. The blast originates at various heights above the ground and is directed toward the ground surface at various angles; it is generated by multiple- as well as single-rotor aircraft. Generally, the downwash-blast characteristics of any aircraft are known or can be estimated with reasonable accuracy. Hence, this study was undertaken to provide basic data on the effects of the flow of downwash blasts on various surfaces under a range of conditions.

Purpose and Scope

Purpose

3. The original purpose of this study was to develop means of predicting the effect of downwash blast from helicopters and other VTOL aircraft on surface soils, ground-protection materials, vegetation, structures, or free objects over which the aircraft might be required to operate. However, it was requested early in the study that the scope be limited specifically to: (a) determination of the feasibility of using lightweight ground covering under VTOL aircraft to prevent soil erosion, dust cloud

* Vertical takeoff and landing.

formation, etc.; (b) determination of the areal extent of ground protection needed and possible means of reducing the areal extent of such protection; (c) limited investigations of soil-stabilization measures for controlling dust during aircraft operations; and (d) correlation of data from prototype and model studies.

Scope

4. Field tests were conducted with operational helicopters at Fort Rucker, Ala., and at the Waterways Experiment Station (WES) to determine downwash velocity profiles. Tests utilizing scale-model rotor blades were then made at the WES over sand and clay soils, a chemically stabilized soil, plastic-impregnated soils, and lightweight ground covers to determine model-scale velocity profiles and air velocities at the ground surface required to dislodge and move particles of the various types of soils tested, as well as the effectiveness of the stabilized soils and membrane.

Definition of Terms and Symbols

5. For clarity, the meanings of certain terms and symbols used in this report are defined below.

Disc loading	The total thrust on the rotor shaft divided by the projected rotor disc area
Propeller	A device having two or more blades which, when mounted on a power-driven shaft, produces a thrust by its action on the air
Static pressure	The force per unit area excited by a fluid on a surface at rest relative to the fluid
Total pressure (also called stagnation pressure)	The static pressure that would be obtained if the flow could be brought to a state of rest isentropically
D	Rotor diameter, ft
h	Vertical height of sensing element above ground surface, ft
K	Classic symbol for constant

P_s	Static pressure, lb per sq ft
q	Dynamic pressure, lb per sq ft
q_m	Jet mean dynamic pressure ($q_m = W/2$ for ducted-fan propeller and $q_m = W$ for open propeller), lb per sq ft
R	$D/2$, ft
T	Total thrust, lb
V	Velocity, fps
W	Disc loading (T/propeller disc area), lb per sq ft
X	Horizontal distance measured on the ground plane from a point directly beneath the center of the propeller hub, ft
Z	Vertical distance from the ground surface to center of propeller hub, ft

PART II: TEST EQUIPMENT AND INSTRUMENTATION

Equipment Used in Model Tests

Truck-mounted test rig

6. The basic test rig used in the scale-model tests was made available to the WES for these studies by the U. S. Army Transportation Research Command. It consisted of a truck-mounted, 14-1/2-ft-long parallelogram boom at the outer end of which was a 128-hp engine, a 5-speed gearbox, and a propeller hub assembly for attachment of ducted fans and open, multibladed propellers. The rig was mounted on the bed of a U. S. Army Model M54, 5-ton, 6x6 cargo truck with a front-mounted winch (see fig. 1). The gearbox provided input-to-output ratios of 1:1, 1.48:1, 2.40:1, 4.38:1, and 7.58:1. The output shaft from the gearbox was attached to a right-angle drive with an input-to-output ratio of 1:2.69. The height of the propeller hub above the ground was controlled by raising or lowering the parallelogram boom assembly with the winch cable of the truck. This height could be varied from 6 in. to 14-1/2 ft. An electric starter, an electric throttle actuator, and a remote control for the engine clutch were located in an operator's remote-control panel.

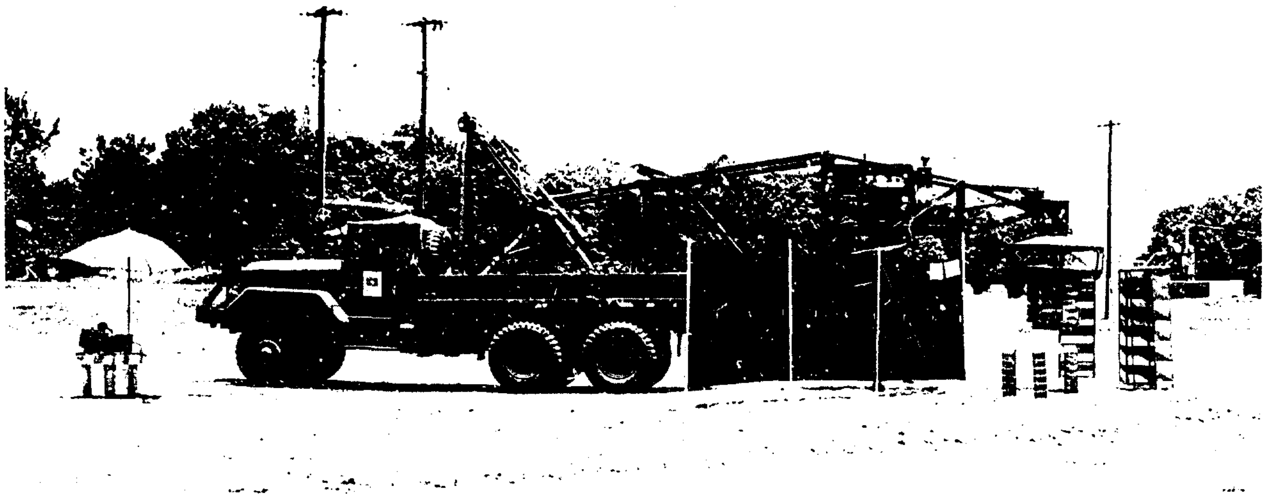


Fig. 1. Truck-mounted test rig

Ducted-fan assembly

7. The ducted-fan assembly consisted of a 3-ft-long duct, a 2-ft-diam propeller with adjustable propeller hub, and a set of straightening vanes designed to remove the swirl from the exiting airstream (see fig. 2).

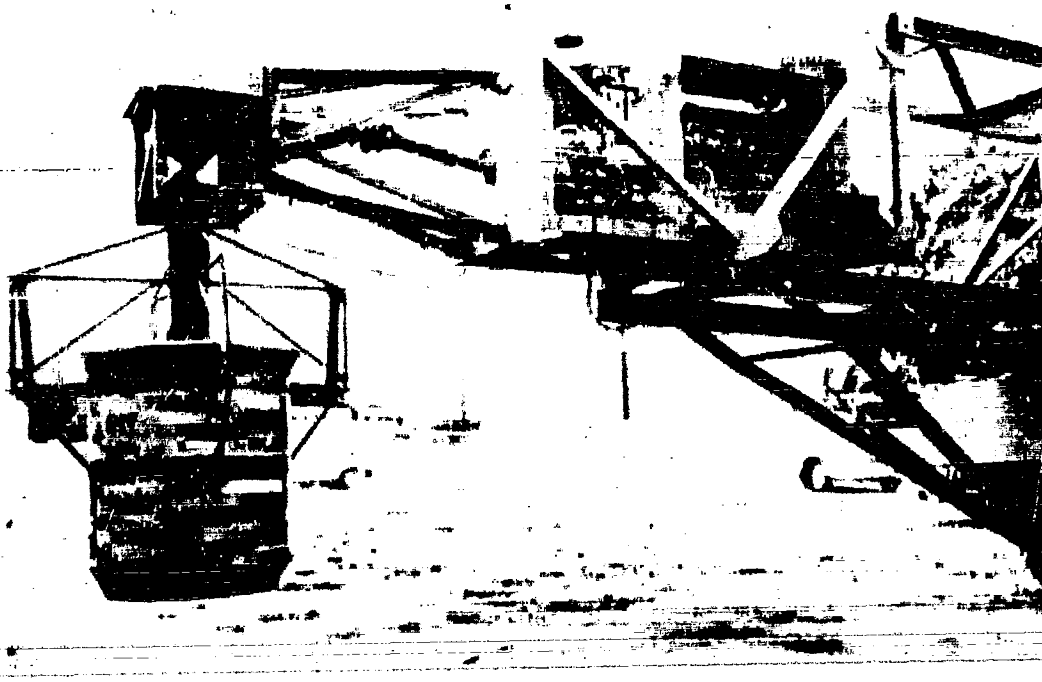


Fig. 2. Ducted-fan assembly

The duct consisted of a laminated cylinder of sugar pine with a lemniscate inlet; the propeller and the straightening vanes were located near the exit. The single-rotation propeller consisted of six 3-in.-chord, RAF-6, airfoil section blades machined from aluminum-alloy forgings. The blades were mounted in a split hub that allowed the pitch of the blades to be manually adjusted. The five straightening vanes were mounted just below the propeller. The duct assembly was mounted on a main support shaft by means of a welded, tubular-steel support. The inlet of the duct assembly was covered with a 1/4-in.-mesh screen to prevent solid objects from falling into the duct. At a speed of 8000 rpm, a thrust of 408 lb could be developed with the propeller-blade tips set at an angle of 17.7 deg.

Propellers

8. Five-ft-diam propellers with two, three, four, and five blades were used in the study. The blades were constructed of wrapped aluminum-alloy sheet to form an NACA 0012, constant-chord (5.75 in.), airfoil section. The two- and three-bladed propellers (fig. 3) were mounted in rigid hubs with the blade angles of each selected to produce the same thrust

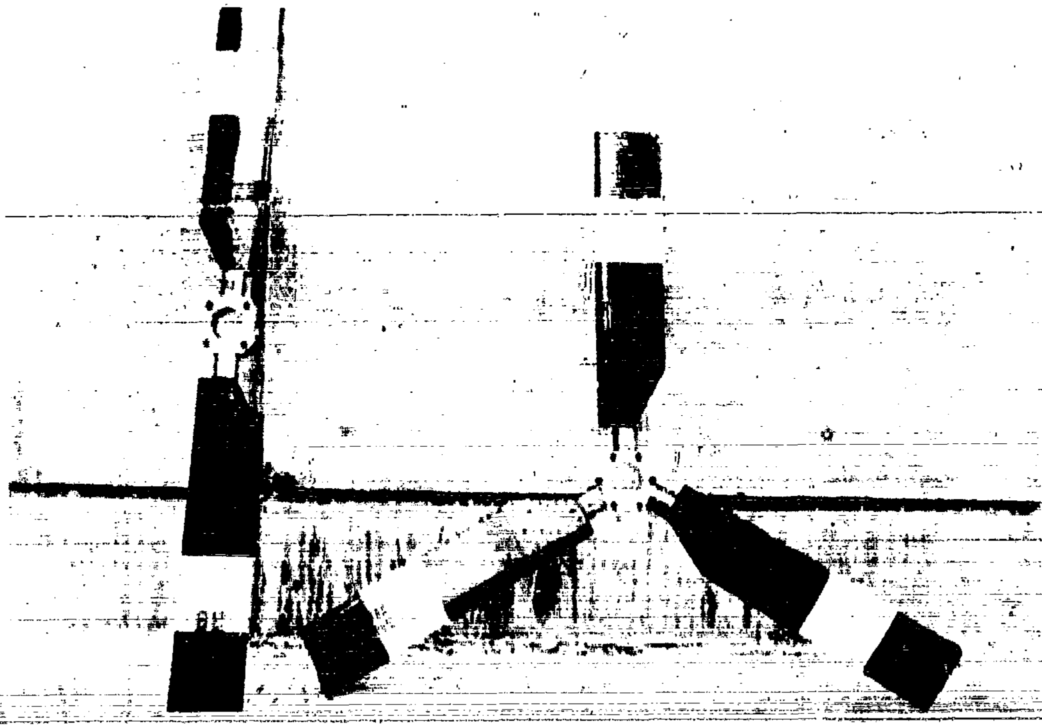


Fig. 3. Propellers, 60 in. in diameter

versus revolutions per minute curve. The hubs of the four- and five-bladed propellers were split to permit varying the pitch angles.

9. A 20-in.-diam, three-bladed propeller, also used in the tests, was mounted on the shaft of a 3500-rpm electric motor (see fig. 4) and on the shaft of a variable-speed electric motor. The propeller was made of cast aluminum; the pitch of the blades varied inversely with the radius. The measured thrust of the propeller on the shaft of the 3500-rpm motor was 15 lb, or a disc loading of 6.88 lb per sq ft; the disc loading with the variable-speed motor varied between 0.5 and 8.5 lb per sq ft.

10. The 24-in.-diam, six-bladed propeller used in the ducted-fan assembly described in paragraph 7 was removed from the test rig and adapted to a variable-speed, electric-motor drive (fig. 5). The blades were set at a 17-deg pitch; the disc loadings varied from 0.38 to 14.4 lb per sq ft.

11. Soil-particle traps were used to catch the air-blown soil during tests of soil-particle movement in order to determine the amount of soil movement caused by the downwash blast from the propeller. The soil trap consisted of eight, 4-in.-high by 4-in.-wide, 6-in.-deep compartments, one

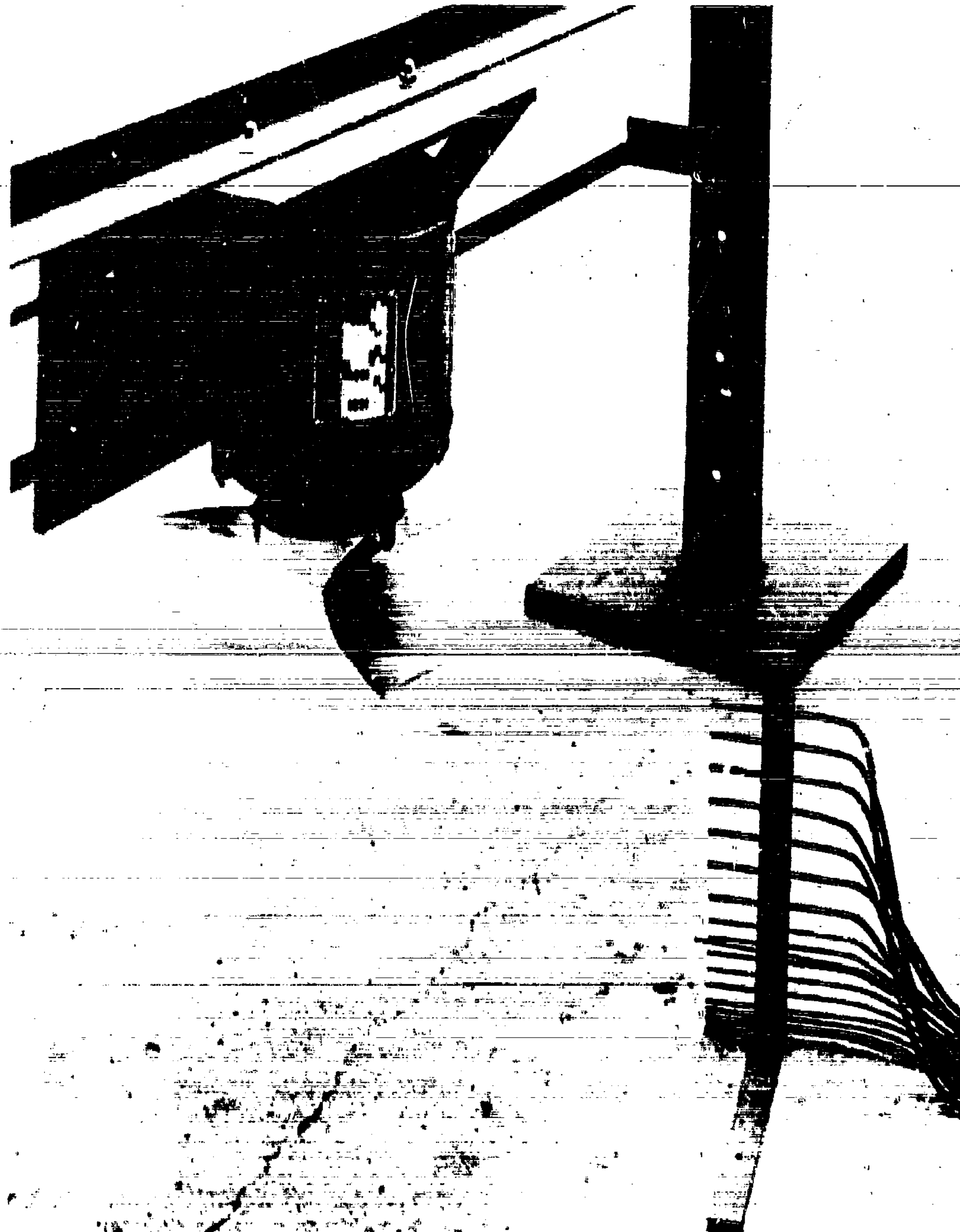


Fig. 4. Propeller, 20 in. in diameter, mounted on 3500-rpm motor

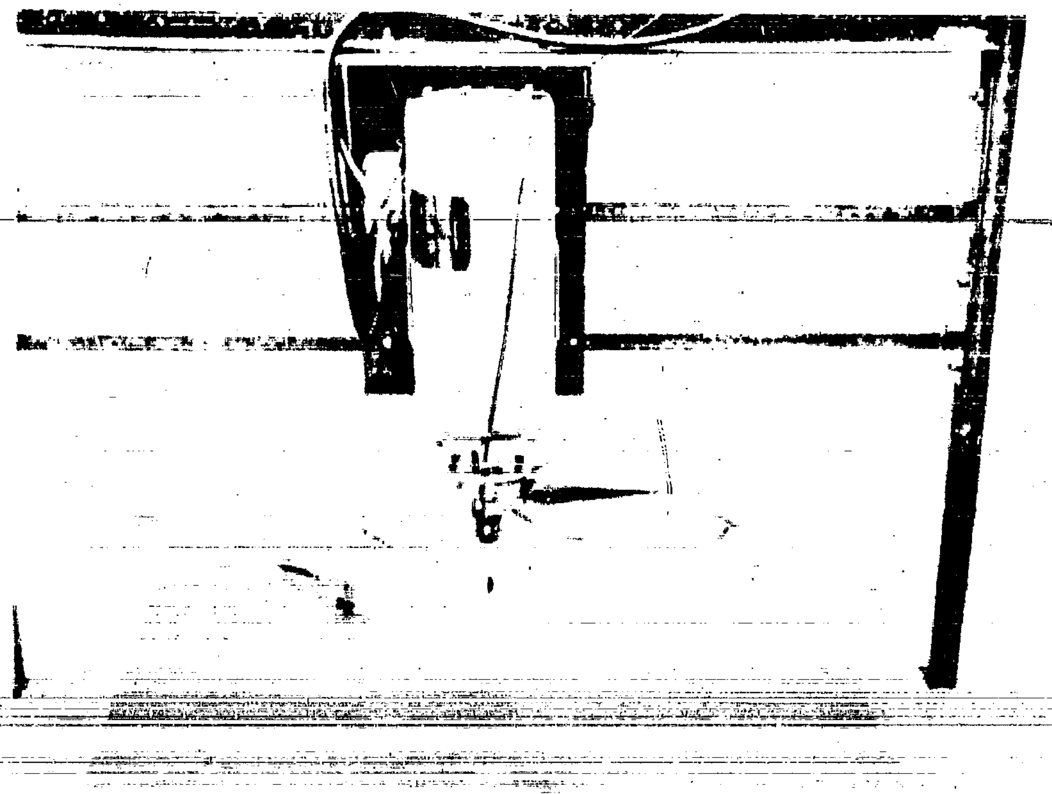


Fig. 5. Propeller, 24 in. in diameter, mounted on variable-speed electric motor

above the other. Each compartment could be emptied individually to determine weight and particle size of the soil collected at various heights above the soil surface.

Instrumentation

12. The instrumentation utilized in this study was in general that installed in the Surface Effects Blast Facility of the WES. Basic electrical recording equipment consisted of commercially available amplifiers, power supplies, magnetic tapes, and an oscillograph; since these are commonly used data-recording devices, they are not described here. Transducers to permit continuous electrical recording of test phenomena were developed as needed. Other devices used to obtain data or operate test equipment under known parameters are described below.

Tachometers used in model tests

13. An electronic tachometer was used to determine accurately the revolutions per minute of the small-scale propeller. A photoelectric cell was mounted on the propeller shaft housing adjacent to a directed light source. This photoelectric cell sensed intermittent reflected light from the propeller drive shaft, which was painted black and white. This arrangement made possible the correlation of revolutions per minute with thrust.

14. A tachometer was also used on the variable-speed drive of the electric motor to determine revolutions per minute of the drive shaft. This instrument consisted of a 60-tooth spur gear and a magnetic proximity-pickup transducer. A pulse was picked up each time a gear tooth passed the proximity-pickup transducer; these pulses were counted by an electronic counter to determine the revolutions per minute of the drive shaft. Thus, calibration of the propellers was obtained as revolutions per minute versus thrust.

Instruments used in both model and prototype tests

15. Pressure sensors. Pressure sensors used in the study to measure downwash velocities consisted of commercially available, aircraft-type pitot tubes, fabricated pitot tubes constructed of concentric metal tubing, and single brass tubes. The pitot tubes measured both total pressures and static pressures; the single tubes measured either total pressure or static pressure, depending on their fabrication. The tubes were connected to either electrical indicating devices or manometers for recording measured static and total pressures. One arrangement of the pressure sensors is shown in fig. 4, page 15.

16. Manometer panel. The manometer panel consisted of 34 inclined glass tubes with a suitable scale attached. Colored vegetable dye was used in the manometer fluid to allow photographs to be taken showing the fluid level. A 4x5 camera mounted above the panelboard made it possible to photograph all the manometer tubes at once; thus, all readings were recorded at the same instant. By using Polaroid film, the records could be read within a short time after they were taken.

17. Pitot tube electrical bellows unit. It was desired early in the study to obtain continuous recordings of surface air velocities with a time base. To do this, a system was designed whereby a mechanical motion was translated to an electrical potential (representing the air velocity) and the change in potential was recorded by an oscillograph. The mechanical motion device consisted of a small bellows unit from an aircraft airspeed indicator mounted inside a sealed container with a

differential transformer. One end of the bellows unit was fixed to the container, with the opposite end free to move. A small iron core was attached to the free end of the bellows unit and suspended inside the differential transformer that was also secured to the container. The total pressure was admitted through tubing to the inside of the bellows unit, and the static pressure from the pitot tube was admitted to the sealed container (outside the bellows unit). As the air velocities increased, the pressure inside the bellows unit increased and caused the bellows unit to lengthen; this moved the iron core within the differential transformer, causing an electrical potential charge within the transformer which was recorded by the oscillograph. Through pretest calibrations, the pressure change could be determined from the oscillograph record. This arrangement made possible continuous recording of the downwash blast velocities at several points over a period of time. Since the unit measured the dynamic pressure, which is the difference between the stagnation and the static pressures, the velocity of the airstream could be computed.

16. Hot-wire anemometers. The hot-wire anemometers used to measure air velocity consisted of a short length of platinum wire that was heated by an electric current. The resistance to flow of electricity through the wire was a function of its temperature. Thus, as air flowed around the wire, cooling it, its resistance changed, and this change was recorded on an electric meter. For continuous recordings, calibration was accomplished by placing the hot wire in an airstream of known velocity and recording the output signal on an oscillograph.

PART III: PROTOTYPE TESTS AND RESULTS

19. Prototype tests were conducted at Fort Rucker, Ala., in March and June 1961 and at the WES in April 1962. The purpose of the full-scale tests was to determine downwash blast velocities beneath the helicopters and along the ground surface during normal takeoff and landing operations for correlation with velocities to be determined in model-scale rotary-wing tests. The H-13, H-U1A, H-21, H-34, and H-37 helicopters were utilized in these tests.

Tests

Fort Rucker

20. In the tests conducted at Fort Rucker, downwash blast velocities were measured both above and along the ground surface. The tests were conducted on a helicopter landing pad (fig. 6) constructed on a bare area over which a membrane ground cover had been placed. The membrane, which gave a relatively smooth surface for the tests, was No. 8 cotton-duck material coated on both sides with vinyl.

21. In the tests conducted in March 1961, the downwash velocities along the ground surface were determined by placing the pitot tube bellows units along a line starting near the point of touchdown of the aircraft. The unit placed nearest the touchdown point measured vertical velocities 1 ft above the landing-pad surface. Similar units placed 10 and 20 ft from the first unit measured both vertical and horizontal downblast velocities. At 10-ft intervals on a staggered line beyond this, hot-wire anemometers were placed to determine the decay of surface velocity with distance. Plate 1 shows the test area layout for these tests. Each of the five

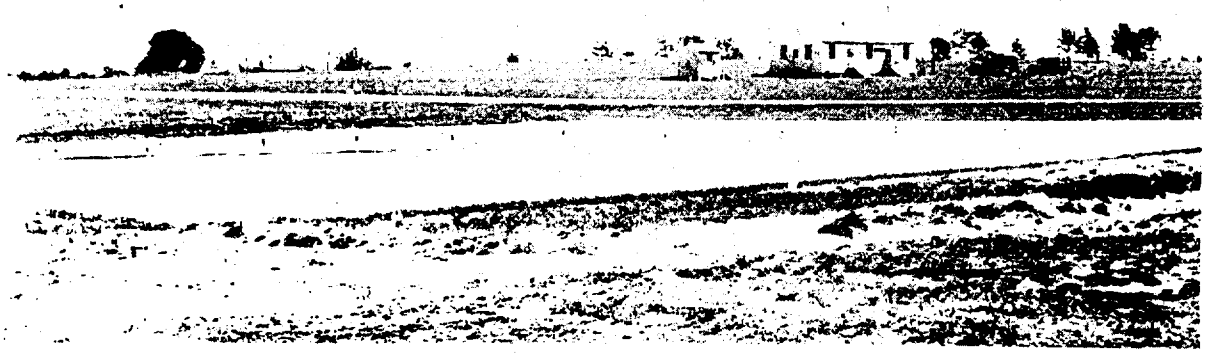


Fig. 6. Test area at Fort Rucker with velocity transducers in place

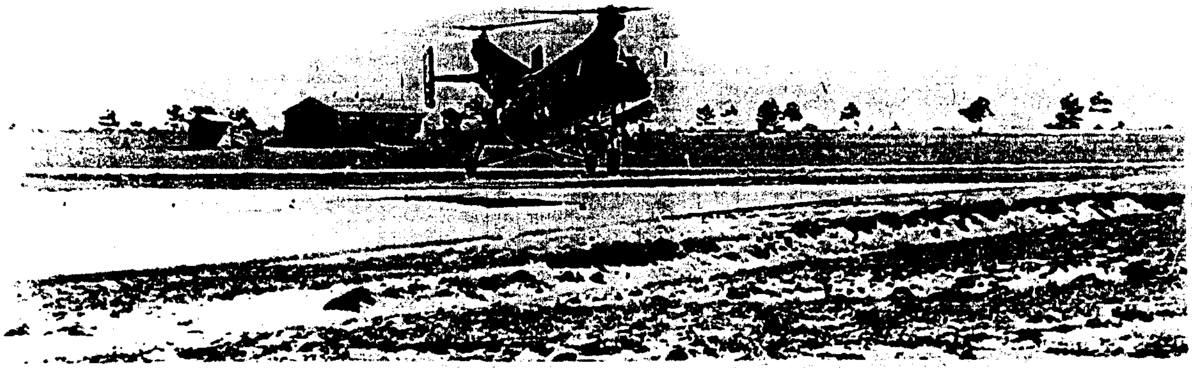


Fig. 7. H-21 helicopter landing on Fort Rucker test area

helicopters was landed in such manner that the center of its rotor was at a known distance from the first probe. Downblast velocities were recorded continuously during the landing-and-takeoff cycle. Two landing-and-takeoff cycles were made with each type of helicopter, one cycle with the fuselage axis parallel to the line of anemometers and one with the axis normal to it. The dual-rotor H-21 was landed several times so that the effects of a single rotor and the combination of both rotors could be observed (see fig. 7).

22. In the June 1961 tests, the downwash velocities above the ground were determined by the electrical bellows velocity pickups supported on a frame which positioned them at given points above the ground surface. The three helicopters used in these tests (the H-21, H-34, and H-37) were landed at various distances from the pickups so that a vertical velocity profile could be obtained at given distances from the rotor blades.

WES

23. The purpose of the tests at the WES was to obtain additional velocity data in the boundary layer (the layer of air adjacent to the ground surface) of downblast from a full-scale helicopter. A temporary landing pad was constructed of steel blast panels placed over a leveled area, with a cloth membrane placed over the panels to provide a smooth surface. Several pitot tubes were placed at selected locations on the surface of the temporary landing pad. The heights of the pitot tubes varied between 1/16 and 30 in. The helicopter utilized was an H-13. Measurements were taken with the helicopter rotor at several heights, ranging from 12 to 50 ft, above the surface and at distances of 75, 52-1/2, 35, and 17-1/2 ft from the pitot tubes. Test data were recorded by photographing the inclined manometer panel and reducing the pressure readings to velocity data.

Test Results

Fort Rucker tests

24. The March 1961 tests at Fort Rucker produced data which appear to be erratic, indicating that the downblast flow along the ground surface either was turbulent or moved in an oscillating or wavy motion and not in a horizontal plane. Maximum surface horizontal velocities recorded during the March 1961 tests as the various helicopters were landing and taking off were as follows:

Helicopter	Maximum Velocity, fpm
H-U1A	3000
H-13	1700
H-21	3500
H-34	3800
H-37	5200

It was noted that these maximum surface horizontal velocities occurred at distances of 1 to 1-1/2 rotor diameters from the rotor shaft center line.

25. Data obtained during the June 1961 tests to develop downwash velocity profiles under the H-37, H-34, and H-21 were as follows:

Distance from Rotor Center Line, ft	Rotor Height ft	Horizontal Velocities, fpm, at Indicated Heights Above Ground			
		18 in.	26 in.	42 in.	50 in.
H-37 Helicopter, 72-ft-diam Rotor					
40	14.1	3000	4200	3500	3600
50		3800	4900	3900	3900
60		4000	5200	3400	3600
70		3800	4700	3300	3300
80		3700	4600	3100	3400
H-34 Helicopter, 56-ft-diam Rotor					
40	9.2	3400	2600	1300	560
50		3100	2400	2300	2100
60		3200	2600	2200	800
70		3400	2600	2400	2300
80		3100	2900	2000	2300

(Continued)

Distance from Rotor Center Line, ft	Rotor Height ft	Horizontal Velocities, fpm, at Indicated Heights Above Ground			
		18 in.	26 in.	42 in.	50 in.
		H-21 Helicopter, 44-ft-diam Rotor			
40	15.4	2700	2100	1900	1200
50		2200	1700	1600	900
60		--	--	400	400

Note: Velocities shown for the dual-rotor H-21 were measured below the front rotor.

The portion of the above-tabulated data representing a distance of about one rotor diameter from center of rotor is plotted in plate 2. The shape of the lower part of the curves is estimated. The exact shape of the velocity profile for prototype data through the boundary layer is not well defined since sufficient prototype data were not available in this area.

WES tests

26. Data obtained in the WES tests with the H-13 helicopter are plotted in plates 3, 4, and 5, which show that maximum downblast velocities, 2100 to 2500 fpm, occurred about one rotor diameter horizontally from the rotor center line. Also, data obtained very close to the ground surface (within 1 in.) indicated velocities sufficient to create large dust clouds, with the upper-air (1 to 8 in. above ground surface) velocities being strong enough to distribute the disturbed soil particles over a large area.

27. It should be remembered that the Fort Rucker and WES prototype tests were conducted with free-flying aircraft, and all distances and heights were approximated by sight; thus inaccuracies are contained in the data. Also, instrumentation error was caused by natural winds blowing at irregular velocities across the test area.

Correlation Studies

28. The correlation phase of the study consisted of correlating downwash velocity profile data of the 20- and 60-in.-diam propellers, and developing a prediction curve for model-to-prototype correlation. Velocity profile data of the various propellers were obtained by placing the pitot tubes at various heights above the ground surface and at various values of X/D. As the propellers developed various disc loadings at various values of Z/D, the dynamic pressures and static pressures were recorded by photographing the manometer board and the downwash velocities were computed. These data were used to determine the boundary-layer conditions as well as the velocity profiles. Fig. 4 (page 15) shows one test setup using the 20-in.-diam propeller and pitot tubes placed at various heights.

Velocity profiles

29. A series of tests was conducted in which various X/D and Z/D values were used with the 20-in.-diam propeller. Then with similar X/D and Z/D values, the disc loading was varied with the 60-in.-diam propeller until the maximum deflection on the manometer panel equaled the corresponding maximum deflection on the manometer panel for the 20-in.-diam propeller. Data obtained at $Z/D = 0.675$ and $X/D = 1.0$ are plotted in plate 6. Data obtained at other Z/D and X/D values correlated fairly well. The disc loading for the 60-in.-diam propeller was 9.05 lb per sq ft, while that for the 20-in.-diam propeller was 6.88 lb per sq ft. It is interesting to note in this case that the ratio of the square roots of the propeller diameters and the ratio of the squares of the disc loadings are the same. If this relation holds true, model-to-prototype scaling becomes a function of disc loadings and rotor diameters as indicated by the following relation:

$$\frac{W_p^2}{W_m^2} = \sqrt{\frac{D_p}{D_m}}$$

Solving for W_m,

$$W_m = W_p \sqrt[4]{\frac{D_m}{D_p}} \qquad (1)$$

where

W_p = prototype disc loading

W_m = model disc loading

D_p = prototype rotor diameter

D_m = model rotor diameter

Additional data are needed for further study of model-to-prototype correlation.

Boundary-layer velocity

30. Ground-surface dust is disturbed by the layer of moving air immediately adjacent to the ground. It was seen from the velocity profiles that the velocity of the boundary layer of air adjacent to the ground surface was slightly less than that of the layer just above it; thus, it is easily seen that once the dust particles are lifted off the ground, they will be quickly blown into the surrounding area. Therefore, maximum downwash velocity is not too important in initiating dust; it is the boundary layer of air adjacent to the ground which initiates it and the upper layers of higher velocity air which distribute it over a wide area.

31. Data from tests utilizing the 24-in.-diam ducted fan were obtained at various values of X/D and under several disc loads and Z/D values, the objective of the tests being to gather sufficient data with which to develop curves and equations that would assist in determining the boundary-layer air velocity when related to given Z/D and X/R ratios. These data are plotted in plate 7 as disc loading in pounds per square foot versus velocity in feet per second. Assuming that the three lines in plate 7 have the same slope, the equation of each curve becomes:

$$W_1 = 0.00193\ V^2 \qquad (Z/D = 0.5)$$

$$W_2 = 0.00252\ V^2 \qquad (Z/D = 1.0)$$

$$W_3 = 0.00295\ V^2 \qquad (Z/D = 2.0)$$

Taking the three above-stated equations of the form $W = KV^2$ and expressing K as a function of Z/D, the general equation form will be

$$K = a + (Z/D)b + (Z/D)^2c$$

Substituting and solving, it is found that:

$$0.00193 = a + 0.5b + 0.25c$$

$$0.00252 = a + b + c$$

$$\underline{0.00295 = a + 2b + 4c}$$

$$a = 0.00109$$

$$b = 0.00193$$

$$c = -0.0005$$

so that $K = 0.00109 + (Z/D)\ 0.00193 - (Z/D)^2\ 0.0005$

and $W = [10.9 + 19.3\ (Z/D) - 5\ (Z/D)^2]\ 10^{-4} \cdot V^2$ (2)

By similar computation and expressing K as a function of X/R,

$$W = [3.667 \times 10^{-4}\ (X/R)^2 + 46.33 \times 10^{-5}\ (X/R) - (27.4 \times 10^{-5})]\ V^2 \quad (3)$$

32. Though these equations were based on results of tests with the 24-in.-diam ducted fan, results of tests with the 24-in.-diam open-bladed propeller compare favorably, as can be seen in plate 8. This plate shows curves computed by means of equation 2, with actual open-propeller data plotted for $X/R = 0$ and $Z/D = 0.5$ and 1.0.

Prediction of velocities initiating soil-particle movement

33. Various materials are available to preclude the dust clouds that are detrimental to helicopter operations, among which are membranes, landing mats, chemicals, and plastics. However, because of the difficulty of transporting large quantities of any of these materials to forward landing areas, the area to be covered should be as small as possible for each type aircraft.

34. To determine the minimum area of protection required for various VTOL aircraft, a prediction curve was developed from data obtained for the 60-in.-diam propellers. This curve, shown in plate 9, represents measured dynamic pressure, q, divided by the jet mean dynamic pressure, q_m, plotted against the radial distance, X, divided by the propeller radius, R. As an example of use of the curve, the test data indicate that the minimum velocity that will produce appreciable movement of fine sand is about 1750 fpm. The dynamic pressure, q, for this velocity is 1.01 lb per sq ft, and the maximum rated disc loading ($W = q_m$ for open propellers) for an overload mission for the H-13 helicopter is 2.59 lb per sq ft, giving a q/q_m ratio of 0.39. From the curve, a q/q_m ratio of 0.39

indicates an X/R ratio of about 3.2. Since the H-13 has a propeller radius of 17.55 ft, the indicated extent of ground cover required to prevent movement of find sand by this aircraft would be a circle about 112 ft in diameter. It is emphasized that the curve in plate 9 is based on model test data and has not been checked against full-scale test data.

Soil Movement and Stabilization Studies

Soil movement velocities

35. To determine the downwash velocities that cause dust-cloud formation, studies were made using the 60-in.-diam propellers to determine the minimum air velocity at the soil surface that causes soil movement sufficient to reduce visibility. For these tests, a 10- by 10-ft test section was constructed, and various soils were placed in the section as testing progressed. To assure airflow parallel with the soil surface, a curved deflector was constructed and placed on the edge of the test section to make the downblast air flow horizontally. A hot-wire anemometer was placed in the airstream at the trailing edge of the deflecting surface to accurately record the velocity of the air passing over the soil surface (see fig. 8). The soils used in the test sections were dry concrete sand and a dry lean clay.

36. The fine particles of dry sand ranging from fines through about No. 50 sieve size were observed to begin moving along the surface at about 1200-fpm air velocity; these particles became airborne at a velocity of about 1500 fpm. The largest particles of dry sand, ranging between about Nos. 4 and 50 sieve sizes, began moving along the surface at an air velocity of approximately 2800 fpm. Tests made on a wet sand showed initial movement of fine particles at approximately 3800 fpm. Tests made on the lean clay indicated initial movement of dust particles at approximately 1800 fpm. It is these dust-size particles which become detrimental to pilot visibility and aircraft operation.

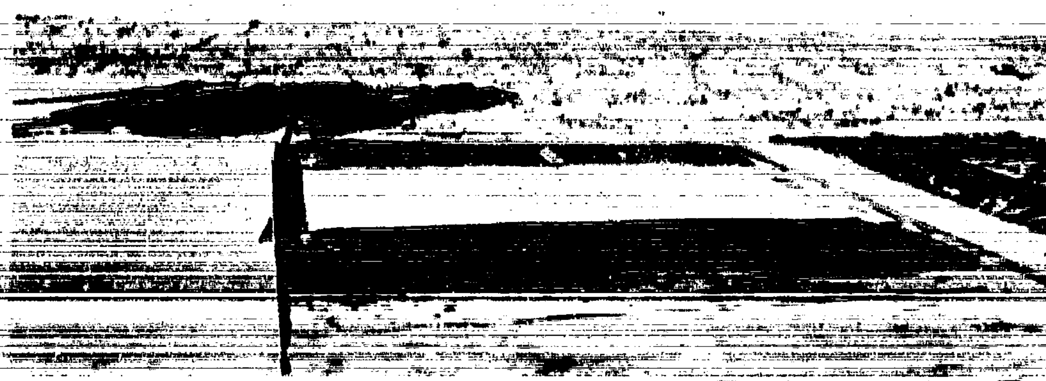
Size of protected area

37. In this series of tests, methods of surface protection were studied which would decrease the dust-cloud formation sufficiently to eliminate occurrence of detrimental conditions during landing and takeoff operations. The test area was otherwise prepared by placing fine sand in the 10- by 10-ft test section. The two- and three-bladed 60-in.-diam propellers were set at various distances from the test section at heights up to 10 ft above the ground surface which was covered with membrane material. The disc loading was maintained at 5.1 lb per sq ft.

Fig. 8. Dust and soil movement test setup

38. Results of these tests indicated that an area 30 to 40 ft in diameter (6 to 8 times propeller diameter) would have to be covered to provide full protection from downwash. Such an area would be excessive for the larger helicopters. In order to study the possibility of decreasing the area requiring protection during the landing and takeoff of helicopters, tests were made using deflectors on the outer edge of the protected area. The deflectors, placed on the front edge (toward the propeller) of the test section, were 6 in. high and sloped 30, 60, and 90 deg from the horizontal (see fig. 9). The 60-in.-diam propeller was placed adjacent to the test section at a distance of 1/2 rotor radius from the deflector and operated at disc loadings of 5.1 and 7.65 lb per sq ft to determine the effectiveness of the deflectors in reducing the areal extent of ground cover required to provide protection against soil erosion and dust-cloud formation. Results indicated that the ground area requiring protection beneath the 60-in.-diam propellers can be reduced about 50 percent (i.e. from about 30 to 40 ft to about 15 to 20 ft in diameter) by the use of a 6-in. vertical (90 deg) deflector.

a. 30-deg deflector



b. 60-deg deflector

c. 90-deg deflector

Fig. 9. Deflectors with sloped faces used on outer edge of test section

Soil stabilization

39. Dust alleviation by means of soil stabilization was investigated. An 8- by 10-ft test area was divided into four sections, each 4 by 5 ft. Two sections were filled 4 in. deep with sand of medium grain size, one section with a fine dune sand, and one with pulverized lean clay. Approximately 1/2 lb of polyester resin per square foot of area was poured onto one of the medium sand sections; it penetrated the sand to a depth of about 1/8 in. Like amounts of a mixture of polyester resin and chopped fiber glass were sprayed on the other medium sand section and the lean clay section, and penetrated to depths of about 1/8 and 1/16 in., respectively. The dune sand was pulvimixed with approximately 0.12 lb per sq ft of aniline-furfural to a depth of about 1/2 in. Fig. 10 shows the stabilized sections as they appeared before the downwash blast tests. The crack in the surface of section 4 in fig. 10 was caused by the shrinkage of the polyester resin upon curing. The fiber glass prevented such cracking in sections 1 and 3. The stabilized sections were subjected to downwash blast of the 60-in.-diam propeller at a disc loading of 10 lb per

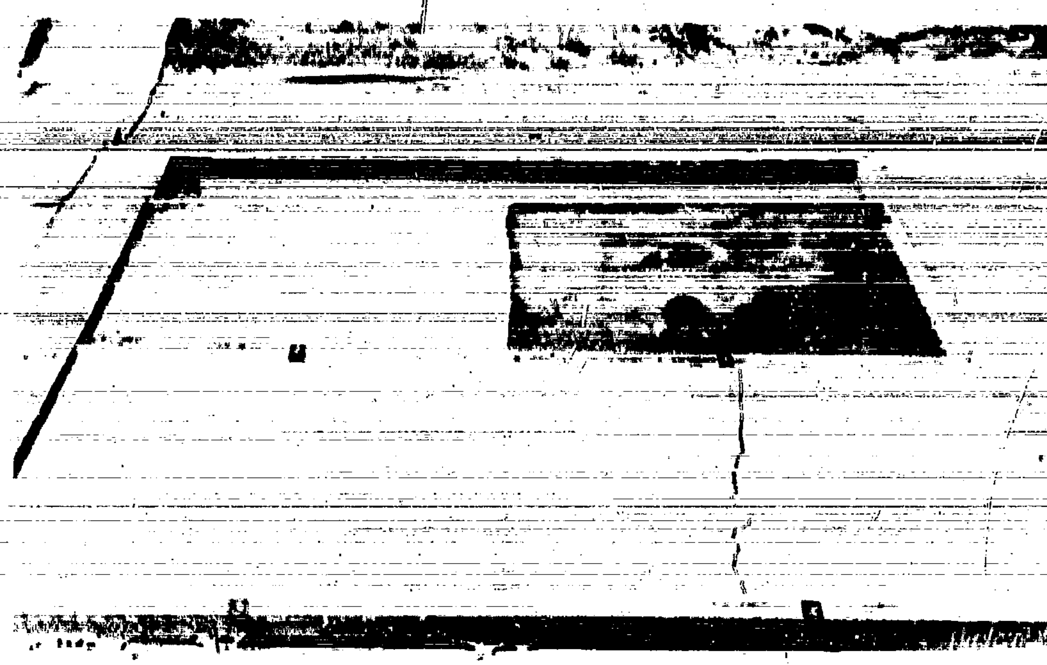


Fig. 10. Soil stabilization sections before test. Section 1 is the treated lean clay; section 2 is the dune sand; sections 3 and 4 are medium sand with polyester resin and fiber glass, and polyester resin, respectively

sq ft with no detrimental effects to any of the four sections. The test sections were then subjected to disc loadings up to 145 lb per sq ft from the 24-in.-diam ducted fan. No damage occurred to the polyester sections; however, an area of the aniline-furfural section (section 2) failed at a disc loading of about 110 lb per sq ft. Failure was caused by the shrinkage cracks (see fig. 10), which allowed the downwash blast to get underneath the stabilized surface. Fig. 11 shows the test area after testing.

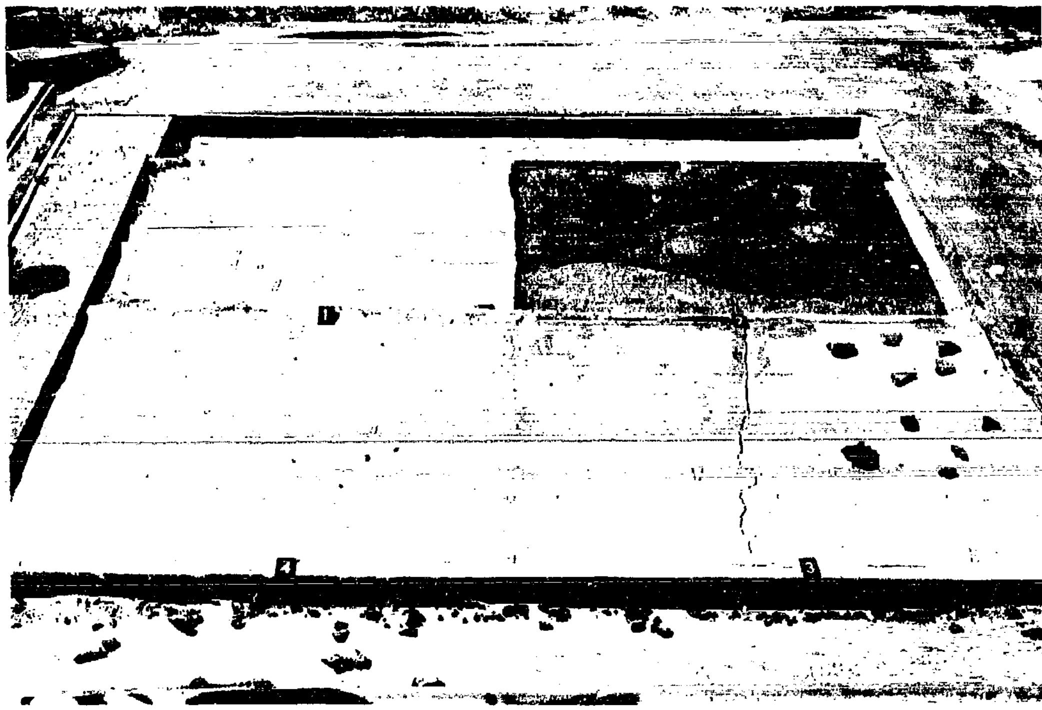


Fig. 11. Soil stabilization sections after test

PART V: SUMMARY OF RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

Summary of Results

Prototype tests

40. Data obtained during the Fort Rucker and WES prototype tests appeared to be erratic in that the velocity readings varied constantly as the helicopter hovered or landed, and the data also varied during the several repeat tests. A large part of this variation of data is attributed to the instrumentation used. The prototype data were obtained early in the study when velocity and pressure pickups were rather crude; refinements of these instruments were used in the later, small-scale tests and not only decreased this variation but indicated the same results for repeated, similar tests. It is believed that the prototype data obtained define fairly accurately the maximum velocities produced by the various helicopters and velocity profile variations both with height above the ground surface and distance from the rotor center line. However, sufficient data were not obtained in the boundary layer (below 6 in.) to definitely define the velocity profile in this critical area. It was noted during the study that maximum surface velocities were greatest at a distance of about one rotor diameter from the rotor center (horizontally) in both model- and full-scale studies. Since this is the area where dust-cloud formation will be initiated as an aircraft approaches for landing or increases power for takeoff, more measurements are needed in this area than in others to define the phenomena.

Model tests

41. Model studies comprised not only boundary-layer and velocity-profile studies (as did the prototype studies), but also studies of soil-particle movement, size of area requiring protection, and effectiveness of soil stabilizers. Boundary-layer and velocity-profile studies were made to attempt correlation with prototype test results; however, it was quickly seen that prototype test conditions could not be controlled as accurately as model test conditions or results measured as accurately. Thus, no satisfactory comparisons could be made. Test data were then obtained on the 20-, 24-, and 60-in.-diam propellers and an attempt made to correlate these data, and through an extension of this procedure to predict prototype results. As is seen in plate 6, this approach to the correlation study produced results which appear favorable; however, the limited data available at this time for both model and prototype do not allow definite conclusions to be drawn. Data presented in plate 7 and discussed in paragraph 31 indicate that boundary-layer velocity varies with disc loading and vertical height. Equations developed for these two small-scale conditions compare

favorably with other similar small-scale data (plate 8), but sufficient data from larger diameter or prototype propellers are not available for comparison.

42. Soil particle movement studies indicated that dust-hazard conditions would develop if boundary-layer velocities exceed 1200 fpm over dry fine sand and 1800 fpm over dust-size particles of lean clay. Thus, ground protection would be required over an area where these velocities were exceeded.

43. As mentioned earlier, the correlation of model and prototype data yielded little information, mainly because of the inability to control exact height and distance of the prototype aircraft from instruments during the tests. Also the presence of wind during prototype testing caused the data obtained to be inaccurate. The correlation of results of tests of the small and large propellers appears to yield usable values although the available data are limited. Additional data are needed on larger model blades and more exactly positioned prototype aircraft to accurately define model-prototype relations.

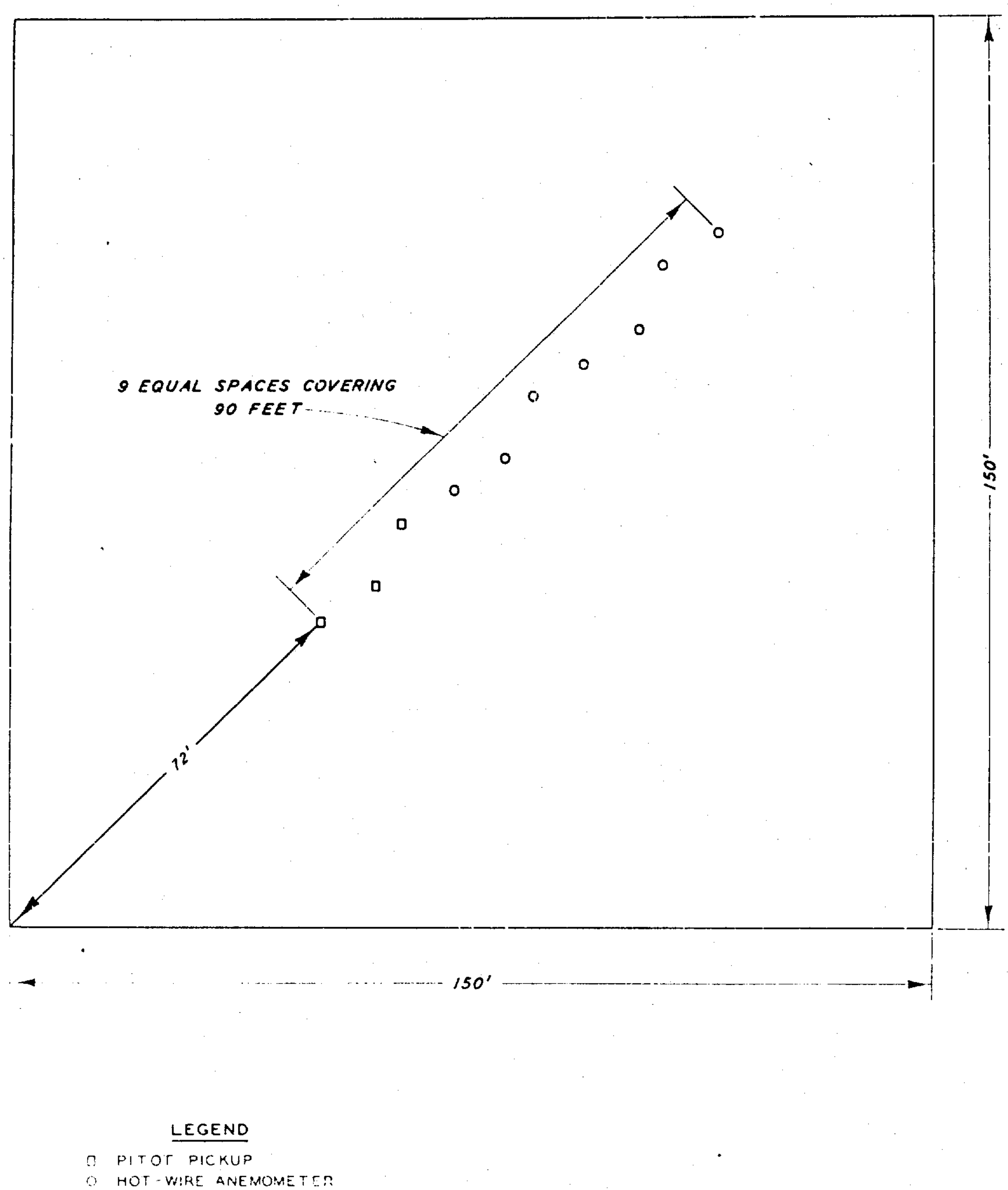
Conclusions

44. Based on results obtained in this investigation, the following conclusions are believed warranted:

- a. The downwash velocities along the ground surface cause soil-particle pickup, and dust-hazard conditions will develop if these velocities exceed 1200 fpm over fine dry sand and 1800 fpm over dust-size particles of lean clay.
- b. Lightweight ground covers (membrane) can alleviate dust in the landing and takeoff area of helicopters.
- c. A vertical lip around the edge of the membrane will reduce the size of membrane section needed.
- d. Certain of the soil stabilizers tested will alleviate dust under VTOL aircraft.
- e. Tests to correlate model and prototype data indicated the need for more accurate measurement of prototype data for each aircraft in order to analyze completely the various parameters involved in scaling and to establish those of paramount importance so that small-scale test results can be used to predict prototype blast effects.

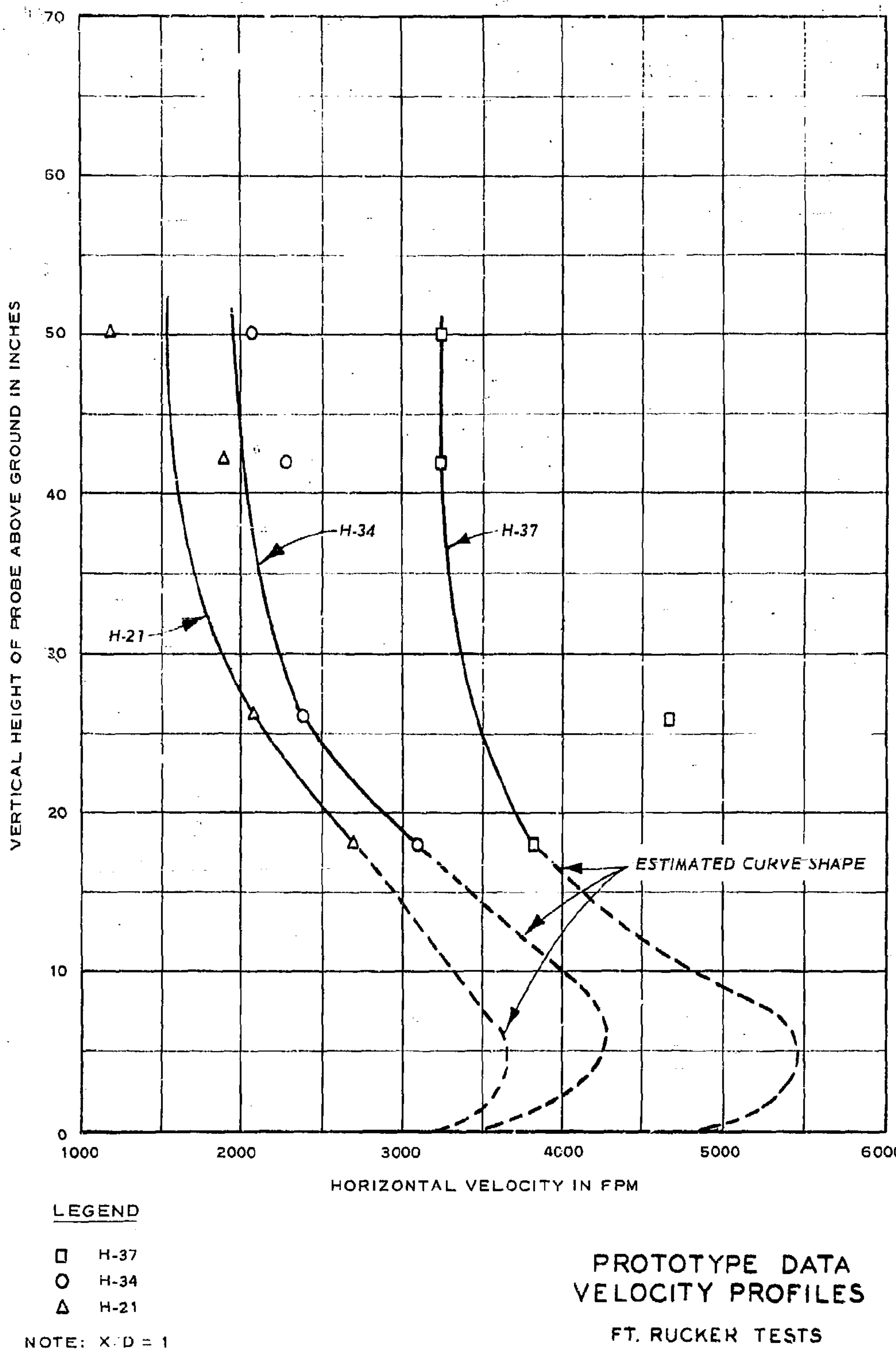
Recommendations

45. In view of the findings presented in this report, it is recommended that the correlation study be continued. Additional tests should be conducted with larger diameter model propellers and with prototype aircraft under rigidly controlled conditions of position and weight in order to establish model-to-prototype prediction curves or equations, or both. Soil movement studies should be continued to determine the factors involved in initial soil-particle pickup and the velocities that cause pickup of various soils in order to predict the area protection required for various helicopters.



FORT RUCKER TEST AREA
LAYOUT

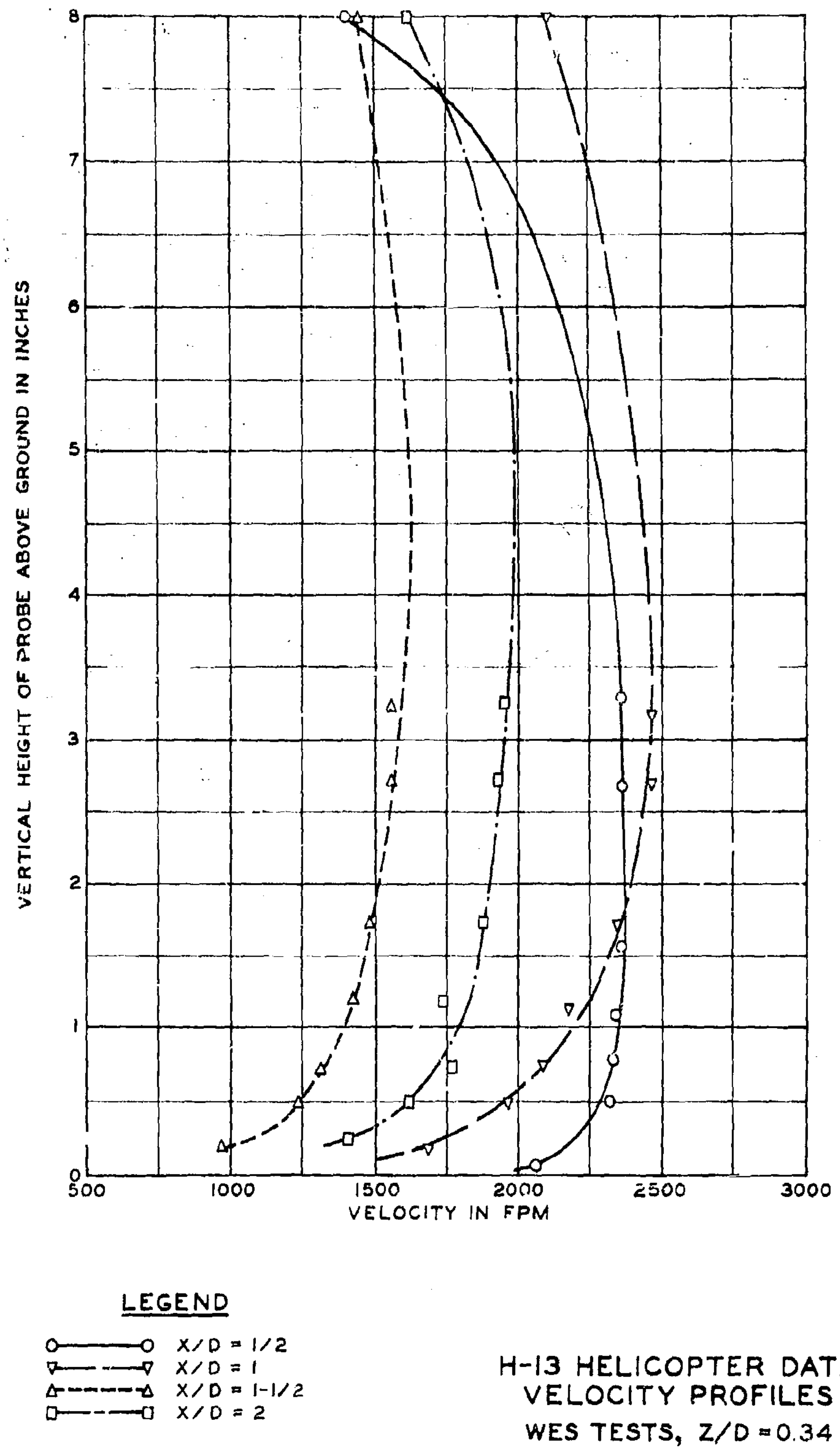
PLATE I



PROTOTYPE DATA
VELOCITY PROFILES

FT. RUCKER TESTS

PLATE 2



H-13 HELICOPTER DATA
VELOCITY PROFILES
WES TESTS, Z/D = 0.34

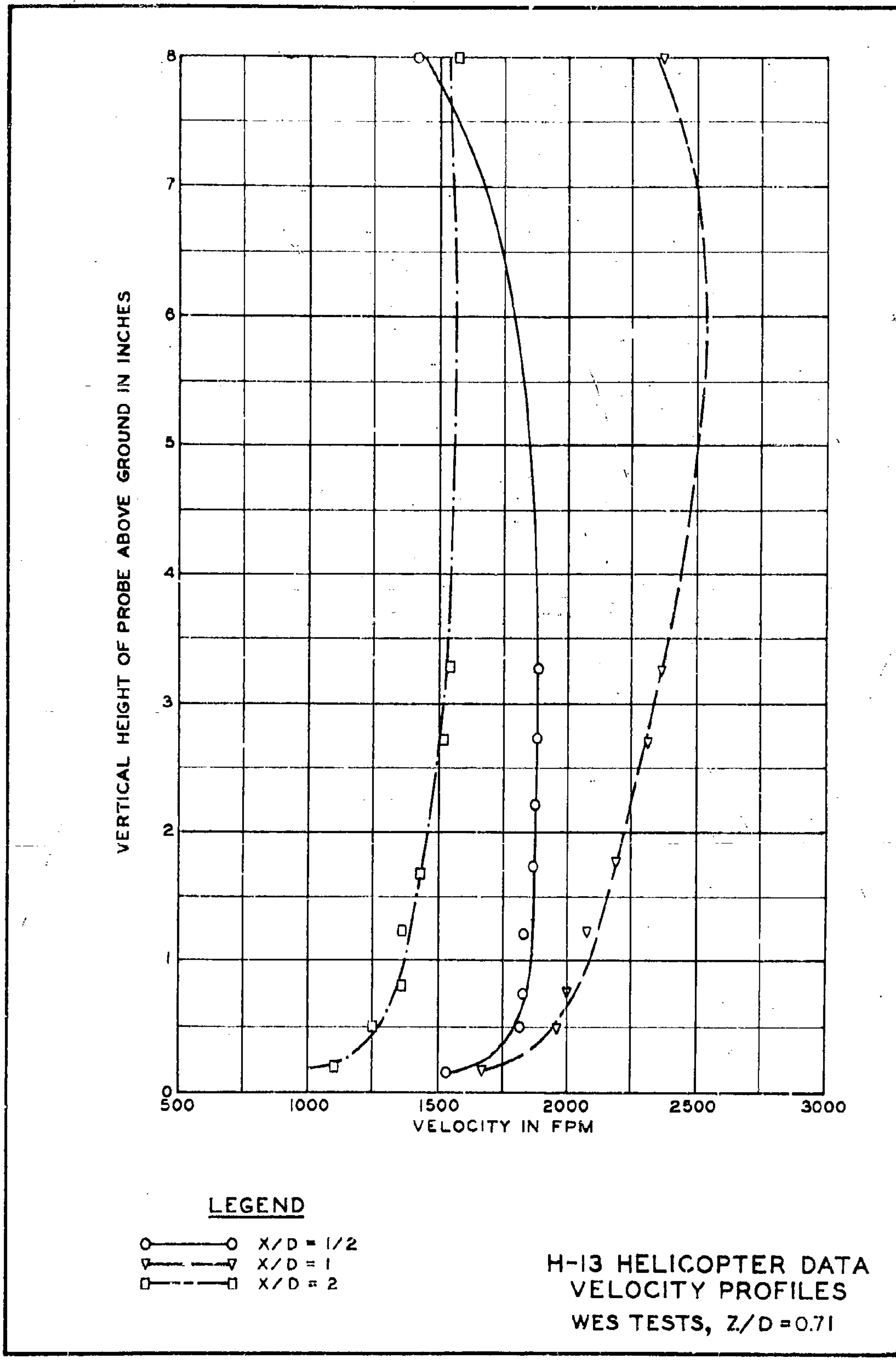
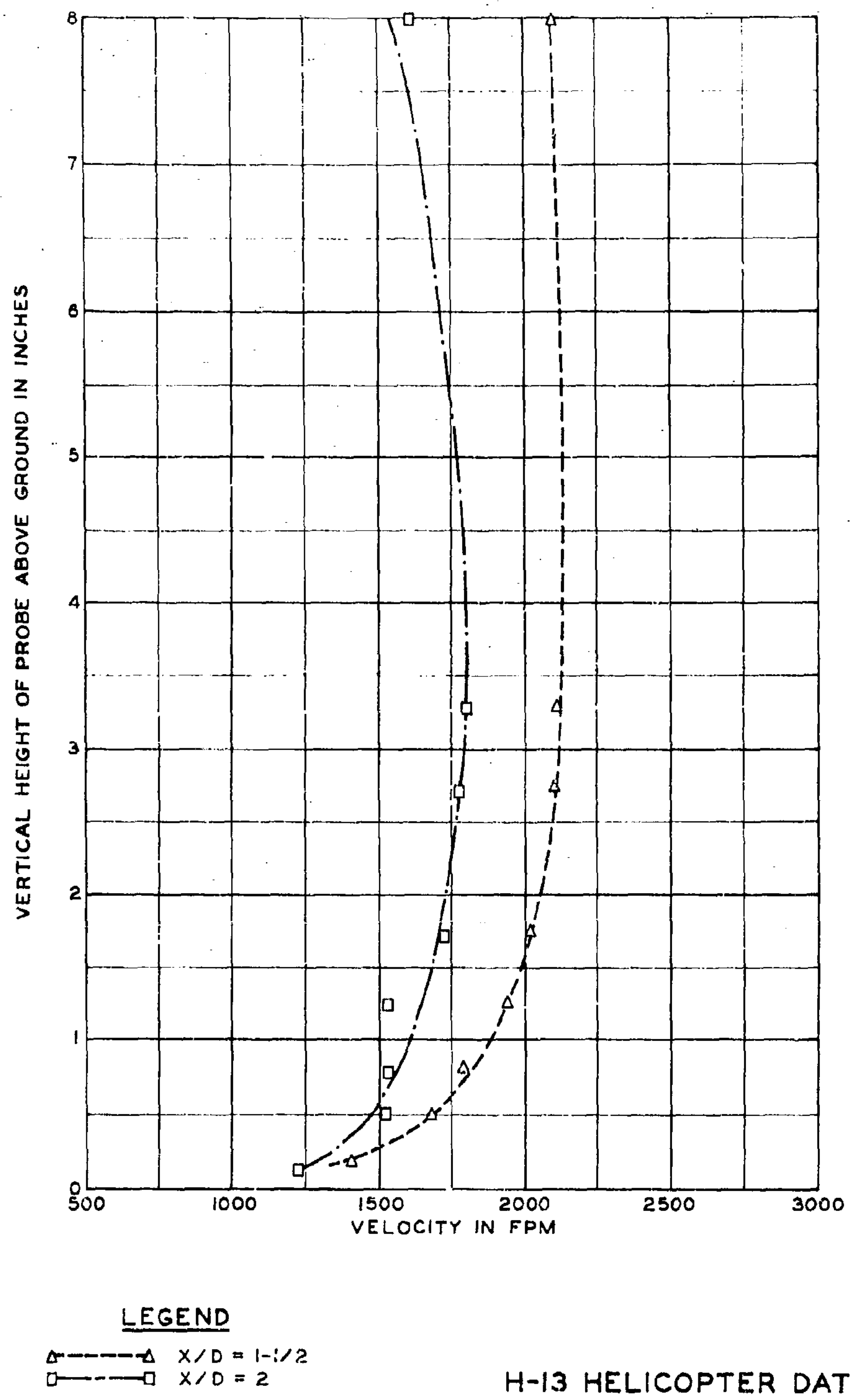
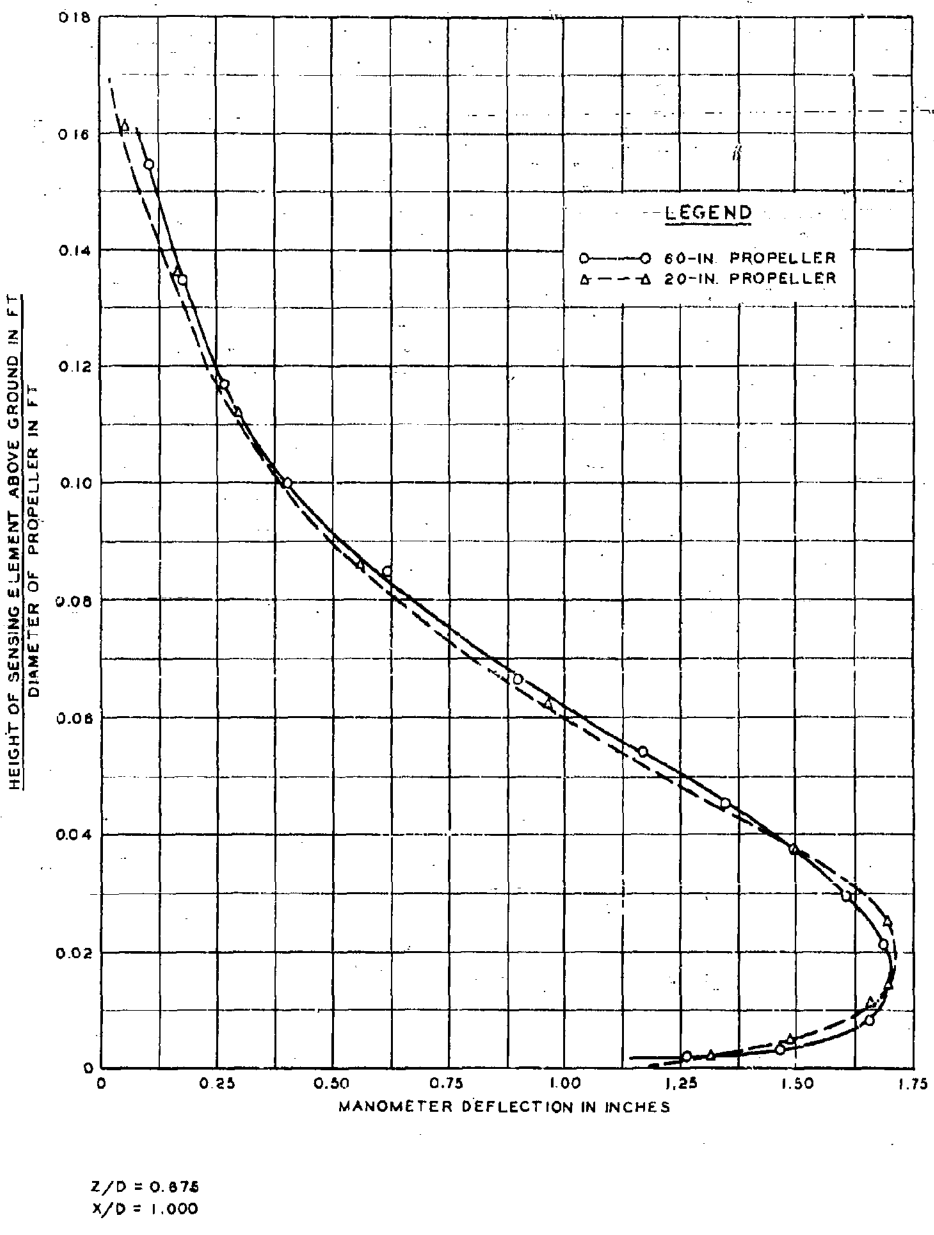

VERTICAL HEIGHT OF PROBE ABOVE GROUND IN INCHES
VELOCITY IN FPM
0
1
2
3
4
5
6
7
8
500
1000
1500
2000
2500
3000
LEGEND
X/D = 1/2
X/D = 1
X/D = 2
H-13 HELICOPTER DATA
VELOCITY PROFILES
WES TESTS, Z/D = 0.71

PLATE 4

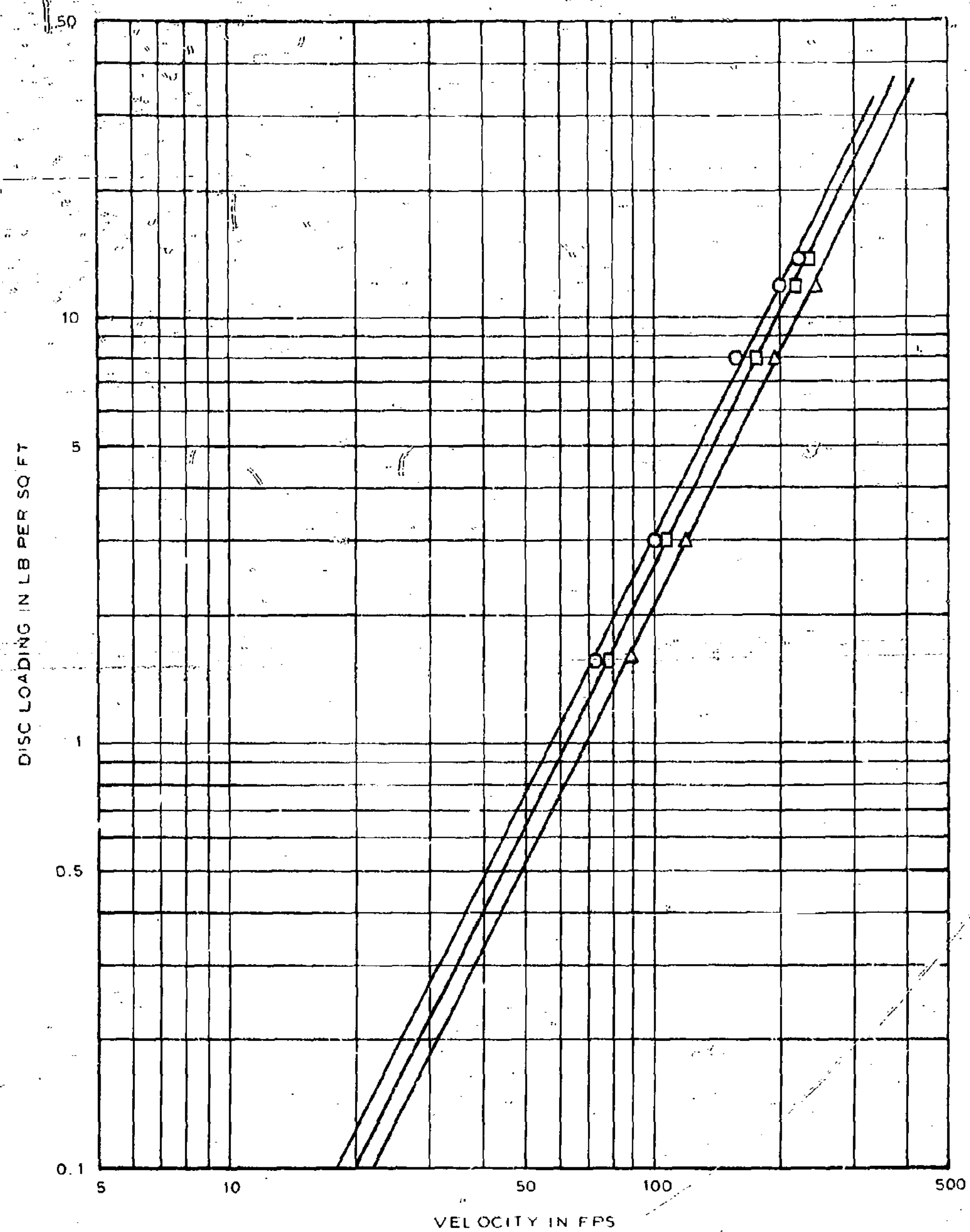


H-13 HELICOPTER DATA
VELOCITY PROFILES
WES TESTS, Z/D = 1.42



CORRELATION OF MODELS
20- AND 60-IN. PROPELLERS

PLATE 6

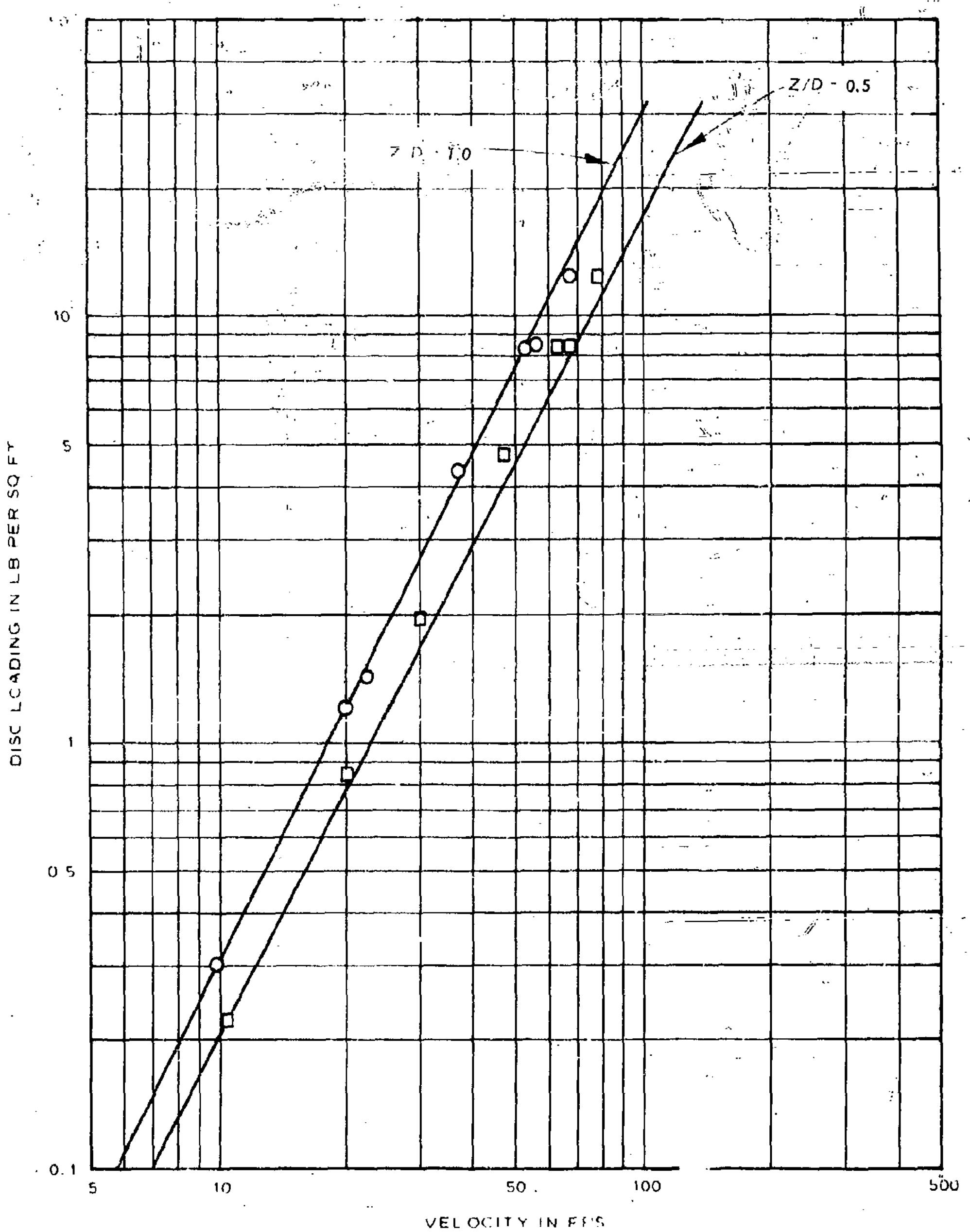


LEGEND

	Z/D	X/R
△	0.5	1.9
□	1.0	2.2
○	2.0	2.4

CORRELATION OF DATA

24-IN.-DIAM DUCTED FAN



LEGEND

COMPUTED DATA

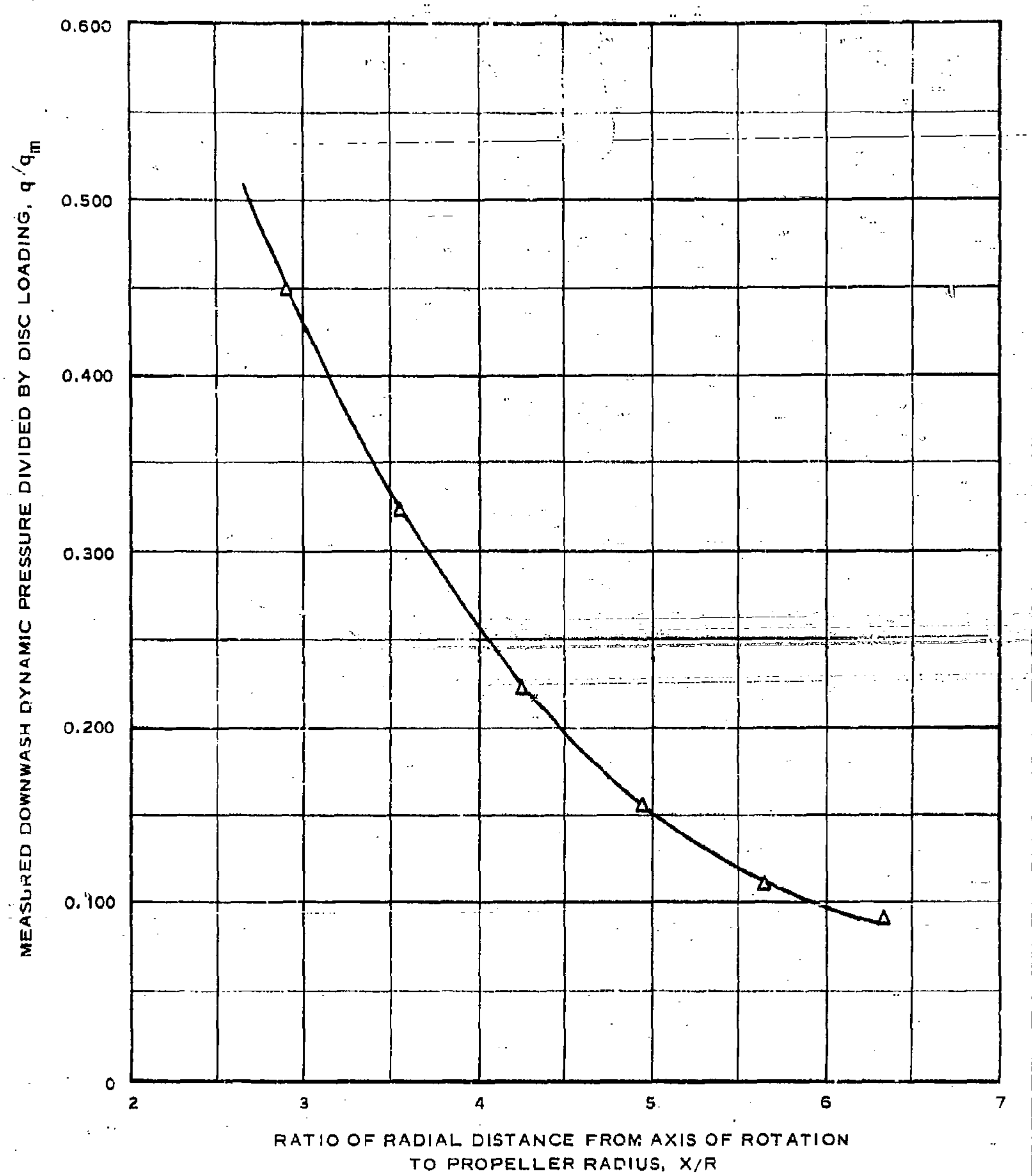
□ ACTUAL DATA FOR Z/D = 0.5

○ ACTUAL DATA FOR Z/D = 1.0

NOTE: X/R = 2

COMPARISON OF ACTUAL AND COMPUTED DATA

24-IN.-DIAM PROPELLER



NOTE: CURVE SHOWN FOR 2- AND 3-BLADED, 5-FT-DIAMETER PROPELLER.
PRESSURES OBTAINED AT $h/D = 0.0333$.

VARIATION OF q/q_m WITH X/R

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13. ABSTRACT

Field tests were conducted with operational helicopters at Fort Rucker, Ala., and at the Waterways Experiment Station to determine downwash velocity profiles. In addition, tests utilizing scale-model rotor blades were made at the WES over wet and dry sands and a dry lean clay, and over a chemically stabilized soil, plastic-impregnated soils, and lightweight ground covers (membranes) to determine model-scale velocity profiles and air velocities at the ground surface required to dislodge and move particles of various types of soil, the size of soil area requiring protection for various VTOL aircraft, and the effectiveness of membranes and soil stabilization in preventing dust-cloud formation. It was concluded that (a) the downwash velocities along the ground surface cause soil-particle pickup, and dust hazard conditions will develop if these velocities exceed 1200 fpm over fine dry sand and 1800 fpm over dust-size particles of lean clay; (b) lightweight ground covers can alleviate dust in the landing and takeoff area of helicopters, and a vertical lip around the edge of the membrane will reduce the size of membrane section needed; (c) certain soil stabilizers tested will alleviate dust formation under rotary-wing aircraft; and (d) there is need for more accurate measurement of prototype data for each aircraft in order to analyze completely the various parameters involved in scaling and to establish those of paramount importance so that small-scale tests can be used to predict downwash blast effects of full-scale aircraft.

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